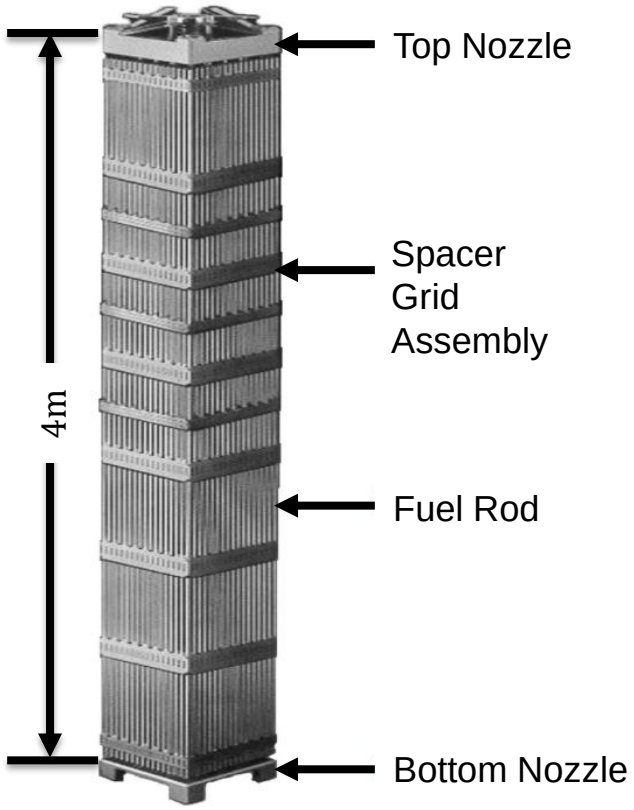
Additive Manufacturing of Spacer Grids for Nuclear Reactors

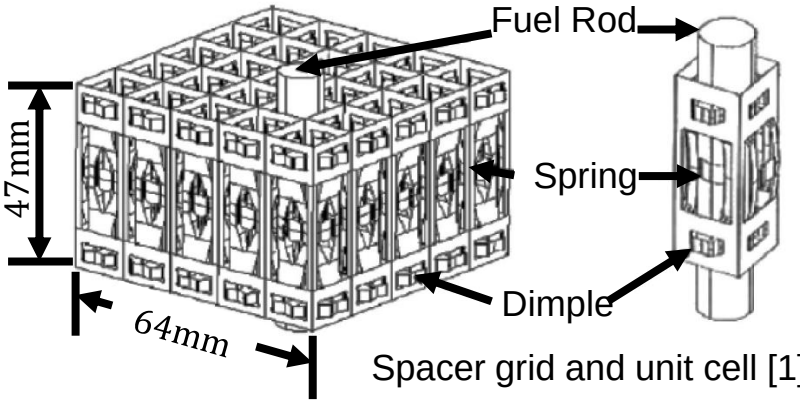
Presenter: Jack Beuth
Carnegie Mellon University
Department of Mechanical Engineering
Co-Director CMU NextManufacturing Center

January, 14, 2020
3 Quarters Into the Project

Background: Spacer Grids



Nuclear fuel assembly [1]



Spacer grid and unit cell [1]

- Spacer grid is a part of the fuel assembly in nuclear reactor
- Interconnected array of punched, slotted sheet metal “grid straps” welded at the intersections
- Spacer grids are expensive to make and it can take 2 years to go from ordering feedstock to completing a component

[1] Nam Song, K., Bum Lee, S., Kyun SHIN, M., Jun LEE, J., Jin, G., Nam SONG, K., … Jin PARK, G. (2010). New Spacer Grid to Enhance Mechanical/Structural Performance. Journal of Nuclear Science and Technology, 47(3), 295–303. https://doi.org/10.1080/18811248.2010.9711957

Additive Manufacturing of Spacer Grids for Nuclear Reactors

Project Objectives

- Overall: Help bring AM processing to the nuclear industry with a first component: *fuel rod spacer grids*
- Nuclear industry is nearly ideal for application of AM
  - High part costs, low volume
  - Replacement parts for existing systems
  - Components for micro reactors and other advanced designs
- Detailed Objectives
  - *Show feasibility* – it has not been done before!
  - *Process changes* to reduce cost
  - *Process changes* to increase performance
  - First *Geometric redesign*: Wall thickness changes
  - *Geometric redesign* to reduce cost, increase performance
  - *Transition* to Westinghouse and their subcontractor Penn United

It is reasonable to expect spacer grids to be manufactured by AM soon after this project completes

Additive Manufacturing of Spacer Grids for Nuclear Reactors

Team

- CMU
  - Jack Beuth, PI
  - Zia Uddin, Ph.D. Student (Student Lead, Processing)
  - Qu He, Masters Student (Process Modeling)
- Westinghouse
  - Bill Cleary: Technical co-PI
  - Clint Armstrong: Technical co-PI
  - Adam Smith: Project Manager
  - Paul Evans: Technical Lead (more than 15 years in fabricating spacer grids)
- Penn United, (Westinghouse AM Subcontractor)
  - Thomas Pomorski:

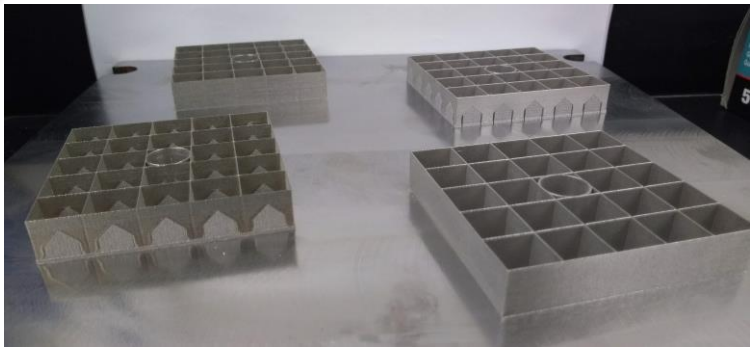
First Builds

Machine and Material
Machine: EOS M290 Laser Powder Bed
Material: Inconel718

Fabrication Parameters

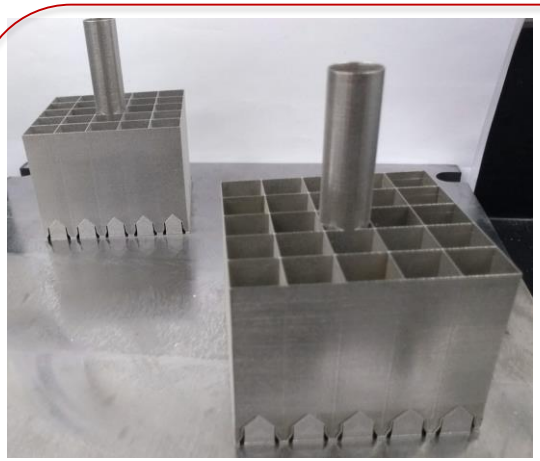
- Preheat: 80°C
- Layer thickness: 40µm
- Power : 285W
- Velocity : 960mm/s
- Hatch Spacing : 110µm
- Stripe Width : 10mm
- Stripe Overlap : 80µm

A Success!



12.5mm high build of the simplified design

- Successful fabrication of parts with 300µm and 500µm wall thicknesses
- Fabrication of the different features is possible using current parameters

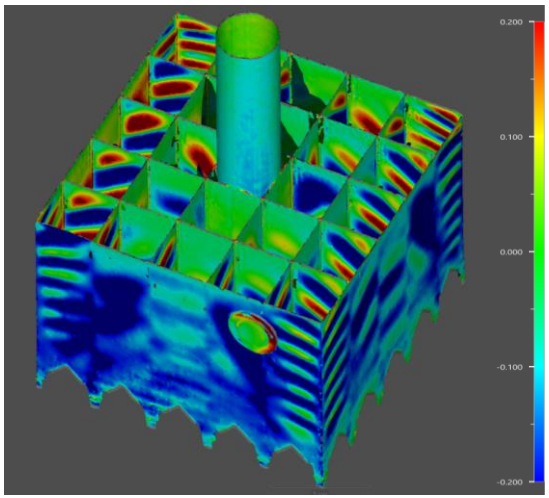


85mm high build of the simplified design

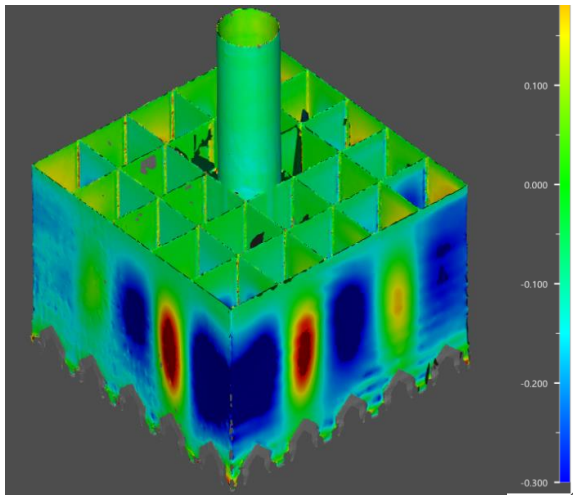
- Using the same parameters as the reduced height build, successful fabrication of parts with 300µm and 500µm wall thicknesses and full height was achieved

Problem: Wall Buckling

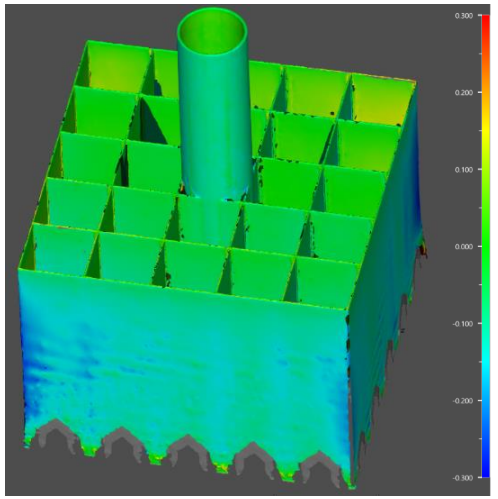
Part Laser Scans:



200 μm wall



300 μm wall



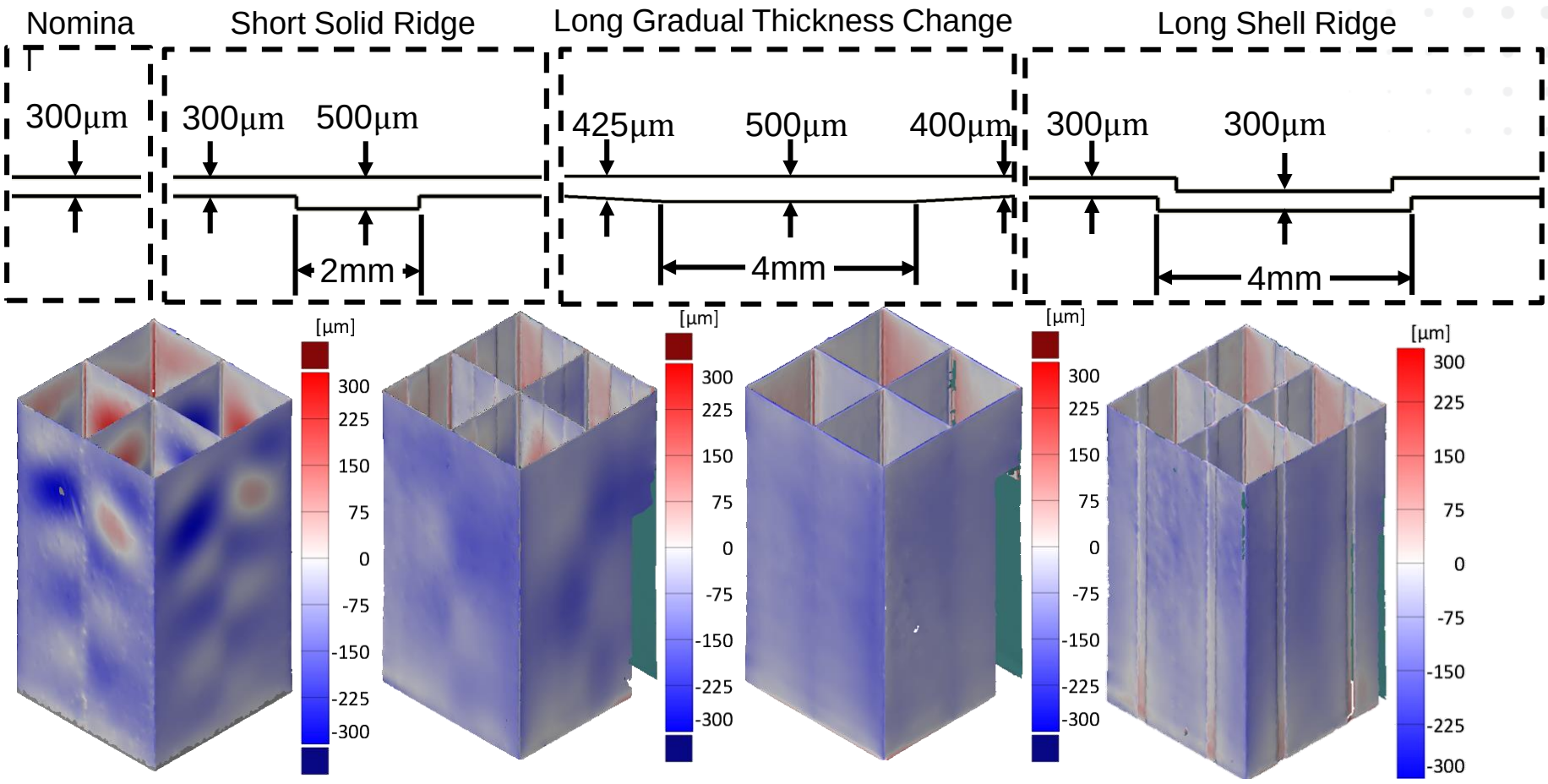
500 μm wall

- 200 and 300μm parts showed buckling with different frequency, direction, and amplitude
- 500μm wall part does not buckle – but some deformation in the corners
- *This is a generic problem for tall thin walls built by AM . . . Not well-explored*

Additive Manufacturing of Spacer Grids for Nuclear Reactors

Project Accomplishments

- **Buckling Solution**



First Cost Estimates

Summary

Job Name	Build time(hrs)	Build time cost(USD)	Total cost(USD)	Cost per part(USD)
1. 500 micron walls 4 parts in one build	20.65	2374.75	2561.69	**640.42**
2. 500 micron walls 1 part in one build	6.57	755.55	827.28	**827.28**
3. 300 micron walls 4 parts in one build	23.44	2695.60	2831.13	**707.78**
4. 300 micron walls 1 part in one build	7.28	837.20	896.08	**896.08**

Detailed

Job Name	Volume (m3)	Volume*1.10	Density (kg/m3)	Cost per kg of powder (USD)	Powder cost(USD)	Build time(hrs)	Build time cost(USD)	Post processing cost(USD)	Total cost(USD)	Cost per part(USD)
1. 500micron walls_4parts_in_one_build	7.312E-05	8.043E-05	8220	192.00	126.94	20.65	2374.75	60.00	2561.69	640.42
2. 500micron walls_1part_in_one_build	1.828E-05	2.011E-05	8220	192.00	31.73	6.57	755.55	40.00	827.28	827.28
3. 300micron walls_4parts_in_one_build	4.351E-05	4.786E-05	8220	192.00	75.53	23.44	2695.60	60.00	2831.13	707.78
4. 300micron walls_1part_in_one_build	1.088E-05	1.196E-05	8220	192.00	**18.88**	7.28	**837.20**	**40.00**	896.08	896.08

Future Plans

- Full Geometry Prints with Springs, Dimples, etc.
- Testing of AM Fabricated Components at Westinghouse
  - Crush, Flow Tests
- Rigorous Comparisons of Build Dimensions vs. Westinghouse Specs
- Cost Reduction through Processing Changes
  - AM offers a lot of room for process manipulation

Additive Manufacturing of Spacer Grids for Nuclear Reactors — Technology-to-Market

- Original Project Plan: Transition AM processing methods to Westinghouse in the last 6 months of the project
  - Since then Westinghouse bought their own AM machine and has it located at Penn United outside Pittsburgh
  - Thomas Pomorski is the AM technician at Penn United and he is now part of this project's team
  - Zia makes regular trips to Penn United for Laser Scans
  - Parallel builds at both CMU and Penn United
- Last group meeting (whole team) at CMU was Dec. 17

Feedback

- Advice to New ARPA-e Researchers: Pick Your Problem!
  - Find a problem that is groundbreaking yet feasible
  - They're hard to find!
- Feedback to Rachel, Pankaj Trivedi, Joel Fetter and ARPA-E:
  - Keep the focus on technicals and transition (so far great)
  - Engagement is high

Conclusions

- AM Fabricated Spacer Grid Feasibility Shown
- First Look at Wall Thickness Changes
- Identified and Solved Buckling Issue
- Preliminary Cost Estimates
- Next:
  - Fabrication of Geometries for Testing at Westinghouse
  - Processing Changes to Reduce Costs